Emerg Med Serv, 2020; VII, 3: 215-223

DOI: 10.36740/EmeMS202003110

REVIEW ARTICLE

TRIAGE AND EMERGENCY MEDICAL MANAGEMENT OF THE ACUTE RADIATION SYNDROME

Arkadiusz Trzos [1,2], Wiktoria Kudła [3], Karol Łyziński [1,4]

1 DEPARTMENT OF DISASTER MEDICINE AND EMERGENCY, CARE CHAIR OF ANAESTHESIOLOGY AND INTENSIVE CARE, FACULTY OF MEDICINE JAGIELLONIAN UNIVERSITY MEDICAL COLLEGE, CRACOW, POLAND
2 ATMED MEDICINE AND EDUCATION, CRACOW, POLAND
3 ACADEMIC CIRCLE OF EXTREME MEDICINE AND DISASTER MEDICINE AT THE DEPARTMENT OF DISASTER MEDICINE AND EMERGENCY CARE, CHAIR OF ANAESTHESIOLOGY AND INTENSIVE THERAPY, FACULTY OF MEDICINE, JAGIELLONIAN UNIVERSITY MEDICAL COLLEGE, CRACOW, POLAND
4 EMERGENCY MEDICAL SERVICES IN CRACOW, CRACOW, POLAND

Abstract

Introduction: Medical personnel of the state Emergency Medical Services (EMS) will be the first element involved in providing assistance to victims of radiation incidents. Triage, initial diagnosis and further patient medical management will depend on their actions. In many radiation incidents, initial radiation triage and early diagnostics will be carried out in the emergency department (ED) or trauma center (TC). Extended triage, diagnosis of ARS and proper treatment will be continued in specialist centers.
The aim: To present a model of patient medical management including initial triage and early diagnosis of ARS that can be carried out at the ED and TC.
Material and methods: The initial medical procedures prepared by expert groups were presented. The choice of procedures was made in terms of the possibility of their application by the EMS teams in Poland. Particular attention was paid to the method of initial triage, based on the clinical condition and laboratory diagnostics.
Results: Based on the material collected, the path of the initial medical procedure was presented. Variants of the radiation triage, interpretation of clinical parameters and results of laboratory tests are presented. The methods of initial treatment and the method of qualification for specialist treatment, and new methods of treating patients were also described.
Conclusions: An adequate evaluation of radiation incidents, determining the absorbed dose of ionising radiation and ARS, as well as initial triage seem to be crucial skills of the EMS workers.

Key words

radiation triage, deterministic effects, acute radiation syndrome

INTRODUCTION

A radiation incident is any event occurring in Poland and abroad involving the use of nuclear materials, ionising radiation sources, radioactive waste products or any other radioactive substances which result in or have the potential to result in a radiation emergency in which ionising radiation threshold doses, specified in the applicable regulations, might have been exceeded, and hence certain emergency medical procedures may be required to maintain safety of workers and the general public [1]. Emergency procedures in the event of a radiation emergency are subject to the regulation of 18 January 2005 on emergency procedure plans in a radiological emergency [2].

Health effects of absorbed radiation may be the result of external exposure to radiation that may be combined with external contamination with radioactive substances; or internal contamination resulting from absorption of radioactive isotopes through inhalation of radioactive dust, swallowing contaminated food products or water or through skin involving direct handling of contaminated material (skin contamination). Those three modes of exposure to radiation may occur together and may be combined with other traumas e.g. thermal, mechanical from a blow. A type of exposure to ionising radiation may determine emergency medical management and priorities of procedures. In the event of radioactive contamination or any assumption that such contamination might have occurred, decontamination procedures shall be started to prevent further radiation [3]. The absorbed dose greater than 1 Gy in case of whole-body or high-dose significant partial-body exposure to radiation results in the acute radiation syndrome (ARS) [4]. In case of subthreshold doses, changes in short-termed peripheral blood values may be noted. Doses greater than 10 Gy are considered to be mainly lethal [5]. In the event of exposure to doses larger than 10

Gy, the bone marrow failure is of minor importance for survival in patients as their survival is dependant on the damages to organs other than the bone marrow such as the lungs, gastrointestinal tract, and cutis since these patients tend to suffer fatal multi-organ failure (MOF) even though the bone marrow aplasia has been successfully managed. Recent data suggests that the average lethal dose of radiation to the whole body that will kill 50% of the exposed population within 60 days (LD50/60) ranges between 3.25 Gy and 4 Gy for patients without supportive treatment and 6-7 Gy for patients treated with antibiotics and transfusion [7]. A concentrated radiation dose may lead to cutaneous radiation syndrome (CRS) without the probability of developing MOF. Beta radiation and low-energy X-ray do not penetrate deep in tissue and induce only cutaneous injuries without any damage to the internal organs [8, 9].

The management of radiation emergencies used so far has been mainly focused on providing medical treatment to individual casualties or a minor group of casualties in places where radiation sources were used, thus the radiation emergency was expected. Moreover, adopted medical procedures have responded only to radiation-induced injuries excluding the impact of other traumas, mostly mechanical ones (post-explosion injuries). The end of the cold war has not limited the radiation threat. In recent years the total amount of scattered radiation material has increased globally. The situation is caused by temporary loss of control over nuclear materials and their uncontrolled distribution, and partly due to an increased ability and apparent readiness of terrorists and criminal groups to use nuclear materials for their own purposes. The use of radioactive materials in "dirty bombs" or constructing and detonating an improvised nuclear device have become common terrorist attack scenarios. Computer simulations of nuclear attacks allow to estimate the number of civil casualties [10, 11]. For instance, it is estimated that more than 500 000 people would be in a damage zone within 2 hours from a 10 kT nuclear detonation in Los Angeles (California, USA) [12]. The prospects of massive human losses are changing medical responders' approach regarding the management of rescue actions performed during radiation emergencies. Therefore, the experience of military medicine is more often taken into consideration.

In case of radiation emergency the national EMS teams are to be involved in the management of rescue actions on both pre-hospital and early hospital stages (emergency rooms, trauma centres). Consequently, the EMS shall take on the responsibility for relevant diagnosis and initial care provided to the injured in the radiation incident. Further diagnosis and specialist care are provided in specialist care centres. The authors of this paper, being aware of the complex nature of medical care management in case of radiation incidents, have focused on triage, diagnostics and procedures that are employed during the rescue actions performed by EMS teams to the patients exposed to large doses of radiation.

TRIAGE

Initial responses of rescue teams in terms of radiation incidents involve assessing medical condition of casualties (triage). Furthermore, certain patients will receive priority intervention at subsequent levels of care. Initial triage based on the ABCD approach enables to decide whether injuries are life-threatening and require an immediate medical intervention. Patients with potentially life-threatening injuries must be primarily treated, and then decontaminated [13]. Once the vital functions are stable, EMS may proceed to triage and radiation diagnostics. Radiation triage guidelines differ from the model commonly used by the EMS teams on a daily basis. Moreover, depending on the scale of an incident, and the number of casualties and the efficiency of emergency services in particular, the interpretation of the results of triage scores may be altered. Radiation triage includes assessing, monitoring symptoms of each ARS stage (prodromal, latent, manifest illness and recovery or death) and calculating the absorbed dose. Samples of tissue are drawn and biometric tests are carried out in order to determine the absorbed dose. Combined-injury casualties (combined traumas) with both radiation and mechanical traumas need to undergo trauma and radiation triage, and thus relevant modification of the results may be required (Table 1).

For the purposes of triage and early diagnostics, methods of clinical assessment and laboratory tests may be employed simultaneously.

CLINICAL EVALUATION

Initial radiation triage of the patient especially in terms of mass incidents may be based on the evaluation of prodromal stage. The onset of symptoms after the exposure, the intensity and severity of prodromal symptoms shall allow to estimate the absorbed dose. Table 2 presents parameters and interpretation of results in this particular evaluation method in detail.

The onset of radiation-induced vomiting and its severity is the most indicative parameter for the assessment of a patient's condition [14]. Other parameters are of lesser importance to assess the severity of the radiation injuries. Body temperature above 37oC within 5 hours after the exposure to radiation indicates the dose of ≥2,5 Gy [15]. The occurrence of early erythema within 6 hours after the exposure may precede the development of the cutaneous radiation syndrome (CRS) [16]. A different model of clinical evaluation is the scoring triage system METREPOL to assess radiation damage to vital organ systems of patients suffering from the ARS: neurovascular (N), hematopoietic (H), cutaneous (C) and gastrointestinal (G). The evaluation of a damaged organ includes symptoms typical for certain damages. Scoring of the patients done by organs reflects damages to organ systems and indicates the most affected ones and potential risks they carry and the best choice for treatment of individuals (Table 3). Each symptom is scored from 1 to 4 according to its degree of severity. A score of 1 implies mild damages while 4 fatal ones. A score of 0 in this protocol means there are no symptoms observed. Having determined (i - degree of severity) the organ specific grading (Ni, Hi, Ci, Gi), the response category is established (RC=?xd) and measured in days (xd) after exposure. The above classification enables the analysis of changes observed in an individual patient and allows to draw a comparison of medical conditions between patients (Fig. 1) [17].

The application of grading codes improves communication between specialists, facilitates national and international communication and interdisciplinary expertise. Coding improves the management of treatment and accurate allocation of the injured.

LABORATORY DIAGNOSTICS

The contemporary ARS diagnostics consists of both observing a patient and specialised diagnostic testing [18]. All persons involved in a radiation incident that have been exposed to ionising radiation should be examined with the use of a biodosimetry during the first 48 hours after the exposure [19]. In the first place a complete blood count (CBC) should be carried out. A CBC should be repeated every 4 hours during the first 8 hours following the exposure and every 6 hours for the next 40 - 48 hours. A CBC analysis is done with special attention to lymphocyte counts which is the easiest and fastest laboratory diagnostic tool to assess the absorbed dose [18]. Lymphocyte depletion is to be observed within 6-24 hours following the exposure [20]. A CBC analysis done after 2 weeks following the exposure has shown leukopenia, lymphopenia and thrombocytopenia. Thereafter, anaemia is observed as well [31]. Lymphocyte depletion rate may suggest the irradiation symptoms in patients who are unaware of having been exposed to ionising radiation. Another solution to be used while denoting the exposure is checking the levels of serum amylase. It has been indicated that any radiation dose greater than 0,5 Gy increases the levels of amylase in blood [21]. Although the level of amylase may increase in other clinical situations, it is worth mentioning that the increase in amylase especially in its salivary fraction may suggest the exposure to radiation [22].

The gold standard for diagnosing ARS is dosimetry of chromosomal aberration in circulating blood lymphocytes. Biological dosimetry enables to calculate the absorbed dose based on the analysis of the radiation damages observed in irradiated cells i.e. the effects of radiation. 6 dicentric chromosomes in 1 000 cells have been observed after radiation of 0.1 Gy. The dicentric chromosome assay (DCA) is employed in case of the exposure with doses of range of 0.1 to 5-6 Gy [23]. The cell division is blocked above this range; thus, this method is found useless for higher doses. Another example of mutations at a molecular level are micronuclei. Micronuclei are not as sensitive to radiation as dicentrics. The detection level is 0.3 Gy. The frequency of the occurrence of micronuclei is directly proportional to the radiation dose. Moreover, due to radiation, chromosomal translocations are present. 4 - 12 spontaneous translocations in 1 000 cells have been detected with a dose of range 0.5 - 5 Gy. It is possible to observe due to a fluorescent in situ hybridization (FISH) technique, which uses molecular probes to visualise specific DNA sequences. An entire chromosome or fragments of chromatin near centromeres of individual chromosomes have been analysed. With doses greater than 5 - 6 Gy it is crucial to detect premature chromosome condensation (PCC). The evaluation of dicentric chromosomes is proved unreliable with higher doses of radiation while PCC is dose-independent so there are no restrictions [24].

TREATMENT MANAGEMENT

Appropriate medical interventions following the radiation exposure at both pre-hospital and early hospital stages (emergency rooms, trauma centres) involve interviewing the patient, physical examination, running additional tests, and based on their results estimating the absorbed dose and introducing symptomatic treatment [25]. Treatment in the prodromal phase focuses on administering antiemetics, antidiarrheals, analgesics, blood transfusion or blood products [26,27]. 5HT-3 receptor antagonists are most effective for vomiting. According to the Radiation

Emergency Assistance Center/Training Site ondansetron, granisetron can be utilized for the treatment and only alosetron is not recommended for gastrointestinal syndrome because it is associated with colonic ischaemia [28]. Anticholinergics or loperamid can be used to treat diarrhoea of patients exposed to radiation [29]. Patients suffering from headaches being the result of radiation should receive widely available painkillers. Acetylsalicylic acid must be given with caution due to a greater risk of bleeding [30]. Any blood products that are given to a patient must be leukoreduced and irradiated with a dose of 25 Gy to prevent transfusion-associated graft-versus-host reaction [31,32]. It is advised to treat with granulocyte macrophage colony-stimulating factor (GM-CSF), granulocyte colony-stimulating factor (G-CSF), and the pegylated form of G-CSF when radiation doses are from 5 to 10 Gy. Patients should be treated with CSFs in the first 24 hours to become effective [13]. Patients with ARS are treated with cytokines such as filgrastim (G-CSF), sargramostim(GM-CSF), pegfilgrastim (pegG-CSFC) [33]. Cytokine therapy should be continued for 2-3 weeks following the exposure or until an absolute neutrophil count equals >1000µL. Interleukin (IL)-12 is also used besides GM-CSF. IL-12 stimulates megakaryocyte growth and unlike cytokines improves patients' survival after irradiation [34]. In irradiated patients with doses greater than 10 Gy administering cytokine therapy is doubtful due to possible lack of stem-progenitor cells. Those patients require a bone marrow stem cell transplantation [4]. New solutions are being constantly searched for to treat ARS even more effectively. Lots of tests have been carried out on animals to get a new perspective on treating ARS. Entolimod/CBLB52 acts as an agonist of toll-like receptor 5 (TLR5). Tests on animal models proved entomolid to lead to a significant improvement in animal survival and neutropenia after exposure with lethal doses of radiation [35]. AEOL 10150 (metalloporphyrin mimetic) acts as an antioxidant and is administered to the patients with acute, radiation-induced lungs injury. The results of one pilot study have indicated that treatment with AEOL 1050 results in reduced clinical, radiographic, anatomic, and molecular evidence of radiation-induced lung injury [36]. 5-androstenediol (AED) is administered with doses of 4-6 Gy and is observed to improve a CBC especially platelets so it becomes useful to treat acute hematopoietic radiation syndrome [37]. When salivary glands get irradiated causing dry mouth and reduced saliva production, amifostine is used [38]. An increased risk of bleeding and blood loss in irradiated individuals require blood platelets transfusion, which is the only available medical intervention to treat thrombocytopenia. Several factors are considered such as interleukin-11, thrombopoietin TPO, romiplostim (a peptide TPO mimetic that binds and activates the TPO-receptor) and eltrombopag (a non-peptide that binds to a transmembrane site on the TPO-receptor) [33]. It is recommended to have platelets maintained at ≥20 000/L in irradiated individuals [39].

SUPPORTIVE THERAPY

In the event of radiation incidents, supportive care should include the administration of antimicrobial agents. The risk of infections is high due to a low number of lymphocytes and neutrophils in the blood and skin barrier and mucous membrane disruptions, which works as a physical barrier to protect from germs. Since immune functions may be impaired, a sanitary regime is highly required in order to prevent transmission of pathogens. The intensity of infections in patients with ARS depends on the virulence of infectious agents, humoral and cell-type responses and an effective phagocytic function [27]. The use of antimicrobial agents depends on the number of neutrophils in blood. If the patient's neutrophil count is >500/µl, then therapy with fluoroquinolones (e.g. levofloxacin) should be chosen. If the patient's neutrophil count is <500/µl, broad-spectrum intravenous antibiotic therapy should be considered. The scheme of intravenous antibiotic therapy may be as follows:

I single-drug therapy: imipenem/cilastatin/meropenem/piperacillin/tazobactam/cefepime / ceftazidime

II 2-drug therapy: aminoglycoside/cilastatin + penicillin or aminoglycoside + cephalosporin

III therapy with vancomycin is limited to specific indications for intravenous monotherapy or combination therapy [40].

Antibiotic therapy should be administered immediately to patients with neutropenic fever. Prominent causes of infections are Gram-positive bacteria (incl. methicillin-resistant Staphylococcus and vancomycin-resistant Enterococcus) and Gram-negative bacteria (incl. Pseudomonas aeruginosa, Escherichia coli, and Klebsiella species) [40].

Immunosuppressed patients exposed to radiation are more susceptible to viral and fungal infections. Acyclovir for viral infections and fluconazole for fungal ones are advised to be administered. Cytomegalovirus and opportunistic Pneumocystis Jirovecii are considered to be important pathogens whose reactivation may be the result of progressive radiation-induced immunosuppression [37].

DISCUSSION

Radiation incidents vary depending on the nature of the event and may pose different threats. Patients at the Emergency Department might have been exposed to radiation a long time before and may have no knowledge of high-dose exposure. Patients may bring radioactive materials into hospital when the substance is deposited on their body surface or clothing unknowingly. EMS teams may be sent to a patient who is in a contaminated environment so it is crucial to take radiation risks into consideration when assessing safety of performed medical interventions. Triage and medical care management happens to be complex. The analysis of radiation incidents showed that the level of irradiation of casualties injured in the same incident may vary depending on the absorbed dose and tissue volume exposed to radiation. Radiation exposures can involve a small part of the body (e.g. arms), larger parts or the whole body. Furthermore, body positioning affects the absorbed dose. Certain exposure to the source of radiation may damage or shield sensitive organs and biological effects of the same dose may be different. The radiation dose may be delivered over an extended period of time (repeated exposures) or as a single exposure to a high dose of radiation. The fact which body part is affected by radiation is of greater importance than an overall dose of exposure. This variability makes standardization of triage process, diagnosing and implementing medical treatment extremely difficult. For that reason the management of medical responses in radiation events is complex and multi-layered. Once an early/initial diagnostic process is performed at Emergency Rooms, patients should be distributed appropriately for different departments depending on the scale of damages to their organs and available resources such as well-trained personnel, equipment and medication. Patients who are likely to develop MOF (RC>3) should be admitted to the intensive care unit; patients with severe and extensive radiation skin lesions should be admitted to the burn unit and all remaining patients to the haematological cell therapy unit. Triage and proper allocation enable an effective use of available resources and improve the efficacy of medical treatment provided.

It is crucial for the medical care management to decide whether patients have residual hematopoiesis, which is common after the radiation incidents since some parts of the bone marrow tend to be underexposed or protected from accidental radiation. The residual hematopoiesis significantly influences a decision-making process of medical teams as hematopoietic stem cell (HSC) transplantation, despite the absorbed dose being high, may be unnecessary. HSC transplantation should not be performed on radiation incident casualties who have the potential of endogenous hematopoietic recovery. Radiation-induced casualties are not advised to have hematopoietic stem cells transplanted due to patients' potential of endogenous hematopoietic recovery. Therefore, emergency HSC transplantation is not necessary in every accidental whole-body irradiation. However, if severe aplasia persists in spite of cytokine treatment for more than 14-21 days, HSC transplantation should be considered. However, in situations where high doses have been delivered, the damage to the bone marrow becomes less relevant and the prognosis of these patients depends on the extent of the damage to organs other than the bone marrow sc. the lungs, gastrointestinal tract, and skin. These patients have a greater risk of developing fatal multi-organ failure MOF, even if the bone marrow aplasia has been successfully managed. Supportive care should include protective isolation (reverse barrier nursing) but that requires an adequate infrastructure and may involve international cooperation. Supportive therapy and specific therapeutic approaches are required in every case. However, the circumstances change radically in the event of radiation disasters, intentional releases of radiological materials on a mass scale, and the use of a nuclear weapon (armed conflicts and terrorist attacks) and the above-mentioned management of triage and medical treatment becomes invalid.

CONCLUSIONS

Initial emergency procedures with patients exposed to high doses of ionising radiation involve various EMS resources. Radiation triage is an indispensable part of medical care management in case of radiation incidents. Early rescue procedures/interventions are as follows: detecting radiation, assessing the radiation doses and their health effects on an individual's body incl. developing ARS. Type of exposure, the radiation-absorbed dose, additional traumatic injuries determine the organization of medical responses. The organ specific grading to assess prognostic aspects of ARS (grading codes: Ni, Ci, Gi, Hi, RC) enables and enhances communication and cooperation between centres in the country and abroad. The increasing risk of radiation events necessitates the management of medical care based on effective triage that is a crucial skill of EMS teams.

1. Triage category depends on the nature and extent of physical injury.

2. Although other injuries may be minimal, treatment guidelines should be followed for patients receiving a whole-body radiation dose greater than 3 Gy.
3. The „expectant" category applies to patients who have no signs of life or suffered fatal injuries with low chances of survival.

Table: 1. Dose-depending triage categories for patients with and without combined injuries.

Conventional triage categories for injuries without exposure to radiation	Changes in triage categories after whole-body irradiation		
	<1,5 Gy	1,5–4,5 Gy	4,5 Gy-10 Gy
Delayed	Delayed	Variable 1	Expectant
Immediate	Immediate	Immediate	Expectant
Minimal	Minimal	Minimal 2	Minimal 2
Expectant 3	Expectant	Expectant	Expectant
Absent	Ambulatory monitoring	Ambulatory monitoring with routine care and hospitalization as needed	

Source: Based on source [41].The military triage system was modified to develop priorities for therapy of irradiated patients and combined-injury patients.
Attention: Military triage is associated with a specific tactical situation

Table 2. Assessment of prodromal phase depending on the amount of absorbed dose of ionizing radiation.

Symptoms	Mild (1-2Gy)	Moderate (2-4 Gy)	Severe (4-6 Gy)	Very severe (6-8 Gy)	Lethal (> 8 Gy)
Vomiting	>2h after exposure	1-2 h after exposure	Earlier than 1 h after exposure	Earlier than 30 min after exposure	Earlier than 10 after exposure
Diarrhoea	None	None	Mild	Heavy	Heavy
Headache	Slight	Mild	Moderate	Severe	Severe
Consciousness	Unaffected	Unaffected	Unaffected	May be altered	Unconsciousness
Body temperature	Normal	Increased	Fever	High Fever	High Fever
Medical response	Outpatient observation	Observation in general hospital, treatment in specialized hospital if needed	Treatment in specialized hospital	Treatment in specialized hospital	Palliative treatment (symptomatic only)

Source: Based on source [23].

Table 3. Overall prognostic aspects of the ARS on the organ specific grading.

Organ system	Grading and severity of damage			
	1: mild damage	2. moderate damage	3. severe damage	4. serious/fatal damage
N	Recovery certain	Recovery with possibile deficyt	Recovery with severe deficit	Recovery most unlikely
H	Autologous recovery certain	Autologous recovery likely	Autologous recovery possible	Autologous recovery most unlikely
C	Recovery certain	Recovery without deficit likely	Recovery with deficit likely	Recovery most unlikely or with serious deficit
G	Recovery certain	Recovery with possibile deficit	Recovery may be possible	Recovery most unlikely

Source: Based on source [30].

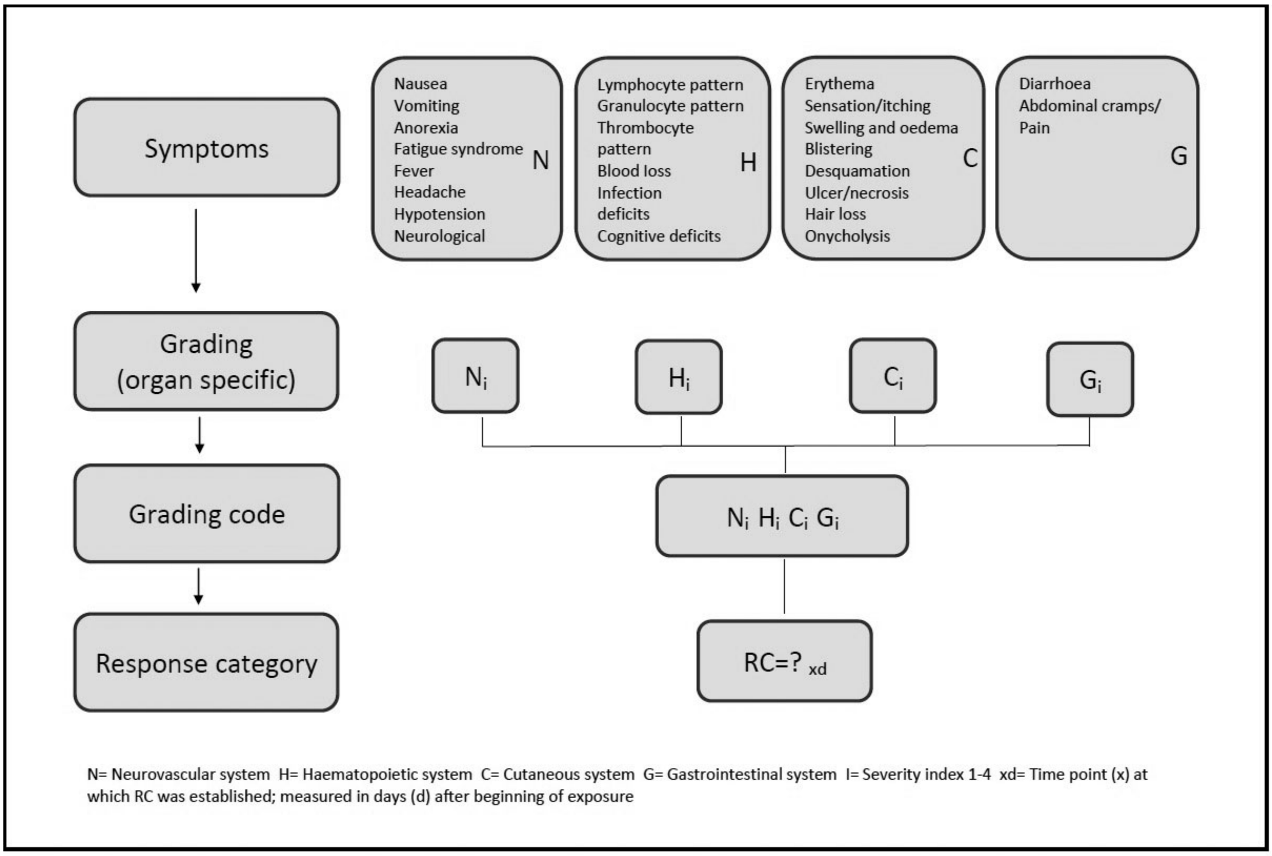

Fig. 1. ARS clinical evaluation. Source: Based on source [30].

REFERENCES

1. Polska Agencja Atomistyki. Zdarzenie radiacyjne. http://www.paa.gov.pl/strona-135-zdarzenia_radiacyjne.html [accessed: 23.01.2020]
2. Rozporządzenie Rady Ministrów z dnia 18 stycznia 2005 r. w sprawie planów postępowania awaryjnego w przypadku zdarzeń radiacyjnych. Dz.U. 2005 nr 20 poz. 169.
3. U.S. Department of Health and Human Services. REMM Radiation Emergency Medical Management: Procedures for Radiation Decontamination: https://www.remm.nlm.gov/ext_contamination.html [accessed: 20.01.2020]
4. López M, Martín M. Medical Management of the Acute Radiation Syndrome, Rep Pract Oncol Radiother 2011;16 (4):138–46.
5. Fijuth J. Radiobiologia. In: Pruszyński B, Cieszanowski A (eds) Radiologia - diagnostyka obrazowa RTG, TK, USG i MR. Wyd. PZWL, Warszawa 2016, pp. 76-77.
6. Hatchett RJ, Kaminski JM, Goans RE. Nuclear and radiological events. In: Koenig KL, Schultz CH (eds). Koenig and Schultz's Disaster Medicine: Comprehensive Principles and Practices. Cambridge, England: Cambridge University Press, 2009, pp. 477-510.
7. Anno GH, Young RW, Bloom RM, Mercier JR. Dose response relationships for acute ionizing-radiation lethality. Health Phys. 2003;84;565-75.
8. Peter RU, Gottlober P. Management of Cutaneous Radiation Injuries: Diagnostic and Therapeutic Principles of the Cutaneous Radiation Syndrome. Milit Med. 2002;167(Suppl. 1):110.
9. https://www.cdc.gov/nceh/radiation/emergencies/criphysicianfactsheet.html [acessed: 27.01.2020]
10. Peter RU. Cutaneous radiation syndrome in multi-organ failure. BJR. 2005;78(Suppl 27,1):180-184.
11. Hick JL, Bader JL, Coleman CN, et al. Proposed "Exposure And Symptom Triage" (EAST) Tool to Assess Radiation Exposure After a Nuclear Detonation. Disaster Med Public Health Prep. 2018;12;386-395.
12. Buddemeier BR, Dillon MB. Key Response Planning Factors for the Aftermath of Nuclear Terrorism. https://www.remm.nlm.gov/IND_ResponsePlanning_LLNL-TR-410067.pdf. Published August 2009. [accessed: 27.01.2020]

13. Waselenko JK. Medical Management of the Acute Radiation Syndrome: Recommendations of the Strategic National Stockpile Radiation Working Group. An Inter Med. 140(12),2004;1037-1057.
14. Wieczorek A, Góźdź S. Zespół żołądkowo-jelitowy Ostrej Choroby Popromiennej In: Janiak M, Wójcik A (eds). Medycyna zagrożeń i urazów radiacyjnych. Wyd. PZWL, Warszawa, 2004, pp. 67-71.
15. Hartman A, Bojar H, Zamboglou N, et al. The significance of clinical prodromes for dosage estimation after whole-body radiation exposure. Strahlenther Onkol 1994;170:538-44.
16. Berger ME, Christensen DM, Lowry PC Jones OW, Wiley AL. Medical Management of Radiation Injuries: Current Approaches. Occupat Med 2006;56(3):162-72.
17. Fliedner TM, Friesecke I, Beyrer K. Medical Management of Radiation Accidents - Manual on the Acute Radiation Syndrome. Published by The British Institute of Radiology 2001, pp.3-13.
18. Donnelly EH, Jeffrey B, Nemhauser JM, et al. Acute Radiation Syndrome: Assessment and Management. South Med J 2010;103 (6):541-46.
19. TMT Handbook. Triage, monitoring and treatment of people exposed to ionising radiation following a malevolent act. https://www.remm.nlm.gov/tmt-handbook-20091.pdf [accessed: 23.01.2020]
20. Macià i Garau M, Lucas Calduch A, López EC. Radiobiology of the acute radiation syndrome. Rep Pract Oncol Radiother 2011;16(4):123-130.
21. Dubray B, Girinski T, Thomas HD, et al. Post-irradiation hyperamylasemia as a biological dosimeter. Radiother Oncol 1992;24:21-26.
22. Hofmann R, Schreiber GA, Willich N, et al. Increased serum amylase in patients after radiotherapy as a probable bioindicator of a radiation exposure. Strahlenther Onkol 1990;166:688-695.
23. International Atomic Energy Agency. Diagnosis and Treatment of Radiation Injuries. Safety Report Series No. 2.Vienna: IAEA, 1998.
24. Pacyniak I. Dozymetria biologiczna. Cytogenetyczna rekonstrukcja otrzymanej dawki promieniowania jonizującego metodą markerów biologicznych. Politechnika Warszawska, Warszawa 2012/2013, pp. 1-43.
25. Peter RU. Cutaneous radiation syndrome-clinical and therapeutic aspects. Radiant Protect Bull. 1996;183:19-25.
26. The medical aspects of radiation incidents. Radiation Emergency Assistance Center/Training Site. REACT/TS. Accessed November 2010. https://orise.orau.gov/reacts/documents/medical-aspects-of-radiation-incidents.pdf [14.01.2020]
27. Berger ME, Christensen DM, Lowry PC, et al. Medical Management of Radiation Injuries: Current Approaches. Occupat Med. 2006;56 (3):162-72.
28. The medical aspects of radiation incidents. Radiation Emergency Assistance Center/Training Site. REACT/TS. Accessed November 2010. http://www.orise.orau.gov/reacts [11.12.2019]
29. Guskova AK, Baranov AE, Gusev IA. Acute radiation sickness: underlying principles and assessment. In: Gusev IA, Guskova AK, Mettler FA (eds). Medical Management of Radiation Accidents. 2nd edn. Boca Raton: CRC Press, 2001, pp. 33-51.
30. Fliedner TM, Friesecke I, Beyer K (eds). Medical Management of Radiation Accidents: Manual on the Acute Radiation Syndrome. Oxford: British Institute of Radiology, 2001
31. Blajchman MA. Immunomodulation and blood transfusion. Am J Ther. 2002;9:389-95.
32. Hebert PC, Fergusson D, Blajchman MA, et al. Clinical outcomes following institution of the Canadian universal leukoreduction program for red blood cell transfusions. JAMA. 2003;289:1941-9.
33. Singh VK, Newman LV, Berg NA, et al. Animal Models for Acute Radiation Syndrome Drug Discovery. Expert Opin Drug Discov. 2015;10(5):497-517.
34. Dainiak N. Rationale and recommendations for treatment of radiation injury with cytokines. Health Phys. 2010;98(6):838-842.
35. Krivokrysenko VI, Shakhov AN, Singh VK, et al. Identification of Granulocyte Colony-Stimulating Factor and Interleukin-6 as Candidate Biomarkers of CBLB502 Efficacy as a Medical Radiation Countermeasure. J Pharmacol Experiment Ther. 2012;343(2):497–508.
36. Garofalo MC, Ward AA, Farese AM, et al. A pilot study in rhesus macaques to assess the treatment efficacy of a small molecular weight catalytic metalloporphyrin antioxidant (AEOL 10150) in mitigating radiation-induced lung damage. Health Phys 2014;106:73-83.
37. Stickney DR, Dowding C, Garsd A, et al. 5-androstenediol stimulates multilineage hematopoiesis in rhesus monkeys with radiation-induced myelosuppression. Int Immunopharmacol 2006;6:1706-13.

38. López M, Martín M. Medical Management of the Acute Radiation Syndrome. Rep Pract Oncol Radiother 2011;16(4):138-46.
39. Culy CR, Spencer CM. Amifostine: an update on its clinical status as a cryoprotectant in patients with cancer receiving chemotherapy or radiotherapy and its potential therapeutic application in myelodysplastic syndrome. Drugs 2001;61:641-84.
40. Hughes WT, Armstrong D, Body GP, et al. Guidelines for the use of antimicrobial agents in neutropenic patients with cancer. Clin Infect Dis 2002;34:730–51.
41. Flynn DF, Goans RE. Triage and treatment of radiation and combined-injury mass casualties In: Mickelson AB (ed.). Medical Consequences of Radiological and Nuclear Weapons. The Borden Institute, U.S. Army Medical Department Government Printing Office, 2013, pp.39-71

ORCID AND CONTRIBUTIONSHIP *

Wiktoria Kudła – 0000-0002-0072-0652 [A,B,C,D,E]
Arkadiusz Trzos – 0000-0002-4390-0901 [A,B,C,D,E,F]
Karol Łyziński – 0000-0003-3292-2459 [C, D]

CONFLICT OF INTEREST

Authors declare no conflict of interest.

ADDRESS FOR CORRESPONDENCE

Arkadiusz Trzos
Uniwersytet Jagielloński Collegium Medicum,
Wydział Lekarski,
Katedra Anestezjologii i Intensywnej Terapii,
Zakład Medycyny Katastrof i Pomocy Doraźnej
ul. Kopernika 19, 31-501 Kraków, Poland
tel. + 48 604 266 992
e-mail: arkadiusztrzos@gmail.com

RECEIVED
04.02.2020

ACCEPTED
07.05.2020

* Contribution: A – Work concept and design, B – Data collection and analysis, C – Responsibility for statistical analysis, D – Writing the article, E – Critical review, F – Final approval.